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1.0 Aerosol Retrieval Over Land

1.1 Algorithm Development

The coded algorithm was tested with four TM images reduced to MODIS resolution size. The results of this test is under analysis.

1.2 Aerosol Models

During the past year we have continued to refine the sulfate and smoke aerosol models. The sulfate model consists of five lognormals of fixed radius and standard deviation which vary in volume according to the aerosol optical thickness. Two of the modes represent the aerosols resulting from gas-to-particle conversion and cloud processes, respectively. Most of the optics in the model are determined by the relative strengths of these two modes as the aerosol optical thickness changes. The smoke model consists of two lognormals of fixed radius and a coarse mode of varying radius. The optics of the smoke model are also dominated by the accumulation mode. The differences between the two regimes result from the fact that the particles in the sulfate accumulation mode grow in size as optical thickness increases while the smoke particles do not. This implies that increasing optical thickness in the sulfate regime is caused not only by increasing the aerosol loading but also by increasing the optical effectiveness of the particles, whereas the increase in optical thickness in the smoke is due solely to the increase in the number of particles. These differences have important repurcusions on aerosol-cloud interactions, remote sensing of aerosol from space and the direct/indirect effect of aerosol on climate change. Our findings were summarized in a paper that was submitted to the volume of bound papers presented at the Chapman conference on Biomass Burning.

We are presently analyzing inverted radiometer data from stations along the Saharan perimeter in order to derive a model for dust aerosol to be used in the retrieval algorithm.

1.3 Inversion of Sun/Sky Radiometer Data and Validation

As part of our work on aerosol modeling we discovered a flaw in the inversion algorithm which calculates aerosol volume distribution from sky radiances. At both the smallest and largest radii the inversion overcompensates for boundary conditions which force the distribution to be zero beyond the resolved range of particle sizes. This creates an appearance of an abundance of unphysically small and large particles. However, this is a minor flaw in that the inversion retrieves a size distribution which accurately reflects the correct optical properties of the aerosol even though the size distribution itself is in error. To correct the inversion flaw we match the single-scattering radiance calculated from the flawed volume size distribution for the first 40 degrees to that of a lognormal distribution in a look-up table. The reasoning is that the inversion must gives us the correct optics for the first 40 degrees. We then correct the volume of the distribution by keeping constant the optical thickness before and after the adjustment. The result of the correction is a physically realistic volume size distribution with the same optics as measured by the instrument. We tested this model by comparing model-generated sky radiances to those measured directly by the sun/sky radiometers and we get excellent agreement.

The modal radii suggested by our models for the accumulation and coarse modes agree well with previous ground-based in situ observations. However, the standard deviations or modal widths of our model tend to be larger than previously observed. Our models stratospheric modes also agree with different measurements of stratospheric aerosol measured in the post-Pinatubo period. We compared our SCAR-A volume size distribution retrievals to airborne in situ measurements of the Univ. of Washington C131A aircraft. Qualitatively the comparisons look very promising. The two data sets both show the major modes in the appropriate size ranges on both hazy days and clear days, when salt is present and when it is not. Furthermore, the in situ data show the same dependence of accumulation mode size on optical thickness although the in situ measured modal widths are narrower and the volume-weighted radii of the accumulation modes are smaller than those measured by the Cimel instruments. Retrievals of aerosol optical thicknesses from the Cimel instruments were also compared with integrations of the scattering coefficient from the in situ measurements. The in situ measurements were able to retrieve aerosol optical depths in the layers in which the plane traveled, but missed aerosol located above and below the level of measurement. A significant portion of the aerosol was located above 2500m during SCAR-A. There is uncertainty in the aircraft measurements as well as the remote sensing instruments so that neither data type is a validation of the other, but the overall agreement of the two measurement methods is an encouraging sign for both, and for the aerosol models derived from the data sets. A paper summarizing the comparison between remotely sensed and in situ measurements of aerosol during SCAR-A has recently been submitted to a special issue of JGR.

1.4 Relationship Between Visible and Mid-IR Surface Reflectance

We are using a relationship between the surface reflectance in the blue and red channels and the reflectance at 2.2µm to develop the method for remote sensing or aerosol over land. Over two hundred targets were chosen from TM and AVIRIS images including different types of forests, other natural vegetation, cultivated fields, exposed soil, sand and residential parts of Norfolk in order to develop the relationship between the spectral channels. Despite the variety of surfaces in these images, the targets were heavily weighted toward moist, green vegetated surfaces in the mid-Atlantic region during the humid summer. Furthermore, surface reflectance was determined only after atmospheric correction. Corrected surface reflectances show that the 2.2 µm surface reflectances are linearly correlated with the visible surface reflectances and that the reflectance at 0.47 µm can be approximated as 25% of the reflectance at 2.2 µm while the reflectance at 0.66 µm is approximately 50% of that at 2.2 µm. Recently we made spectral measurements using two field spectrometers in San Diego. These new data will contribute information on the spectral reflectances of dry, olive-green vegetation in an arid environment. The recent data was taken at the ground or from low-flying aircraft requiring little atmospheric correction and thus should increase our confidence in applying the aerosol over land algorithm to more arid regions of the globe. A paper is in preparation on this subject.

2.0 Aerosol Retrieval Over Ocean

The algorithm for remote sensing of aerosol properties over the ocean was written. An analysis of the physical information content in the spectral radiances to be measured from MODIS over the ocean was summarized in a paper (Tanr_ et al.,) that was accepted for publication. The analysis shows that in addition to information on the aerosol loading or optical thickness, it is possible to derive the ratio between the accumulation and coarse particle mode, assuming that there are two modes in the atmosphere. The effective size of the dominant mode can also be obtained. A second paper on the actual MODIS algorithm is being written for the special JGR issue devoted to the remote sensing workshop.

Validation of the algorithm had began using data from the SCAR experiments and older data from Africa.

3.0 Algorithm for Detection of Fire Properties

3.1 SCAR-C Data Analysis -- MAS calibration

There are three separate calibrations being performed on the SCAR-C MAS data, the visible channels, the thermal channels at background temperatures and the thermal channels at high fire temperatures. To calibrate the visible channels NASA/Ames personnel used the NASA/Ames integrating sphere characterized by John Cooper of NASA/GSFC. The resulting visible channel calibration was used in an intercomparison with AVIRIS flying on the same mission. The results of the intercomparison show that MAS agrees with AVIRIS in calibration slope but that there are offsets between the two instruments. The offset is insignificant at 0.55 µm, but as much as 0.05 in reflectance units at 0.87 µm. A second intercomparison from the same flight but several hours later which also included some scenes of clear ocean also show offsets between the two instruments in some channels. Reflectance of ocean targets in AVIRIS are less than 0.005 for

1.64 µm while reflectance for MAS in this channel for the same targets are -0.02. Ocean targets at 0.87 µm for AVIRIS have 0.02 reflectance while for MAS the reflectance is 0.06. The AVIRIS results over the ocean targets are much closer to physical expectations than MAS . This is due to the more rigorous calibration procedures for AVIRIS and because AVIRIS is thermally controlled in flight while MAS is not. In all future analysis of SCAR-C data we intend to adjust the MAS data to AVIRIS values.

The background temperature calibration is proceeding well by using the onboard calibration procedure. We have retrieved some useful results. However, there are still some problems with the 3.9µm channels. Also high temperature calibration is disappointing. Initially we had hoped to calibrate for fire temperatures by using a hot plate technique developed by Jim Brass at NASA/Ames. Unfortunately this technique produced unusable results. We are trying to extrapolate the onboard calibration procedure to the higher temperatures but are uncertain of our accuracy. Recently Ken Brown has used a multi-channel approach to make a quadratic extrapolation to high fire temperatures for one of the 3.9 µm channels. His results look promising and are currently being analyzed for accuracy and consistency. If his extrapolation does not work to our satisfaction we will have to rely on the 1.64µm channel for quantitative fire information.

4.2 SCAR-C Data Analysis -- Fire Analysis

We have analyzed the Quinault fire which is a prescribed fire that sent a well-defined smoke plume over the ocean and a second prescribed fire (ITT fire) that sent its plume out over land. There are eight ER-2 observations of Quinault and six observations of ITT over a two hour period. We have related the size of the fire to the amount of smoke by plotting both quantities as a function of time. We also have related the emitted thermal energy to the smoke and compared both to similar quantities predicted by the USFS models. Our results show clearly the relationship between fire thermal energy and fire emissions and how these quantities can be monitored by remote sensing. In doing this analysis we have modeled the fire thermal energy as a function of wavelength and pixel size and have found that for MAS-size pixels, the 1.64 µm channel is as sensitive to the fire as the 3.9µm channel is for MODIS-size pixels. All quantitative analyses of the Quinault and ITT fires thermal energy were done using the better-calibrated 1.64 µm channel. Our results were summarized in a paper submitted to the volume of the Chapman conference on Biomass Burning. We are repeating this analysis for other SCAR-C fires. Eventually we will integrate our findings with those measured in situ by the Univ. of Washington's C-131A aircraft.

These data along with SCAR-B data will provide the basis for the development of the MODIS fire algorithms.

4.0 SCAR-B

The smoke, cloud and radiation experiment in Brazil, SCAR-B, led by members of our group took place August 16 - September 14, 1995. Overall, the experiment was a great success and meets the scientific expectations of the participating scientists. It has produced a unique and unprecedented large data base to study the effects of biomass burning on atmospheric processes and climate, and to prepare new techniques for remote sensing of these processes from space. We expect to spend several years retrieving valuable science from the data set.

Twelve missions were flown by the NASA ER-2 aircraft over an area of 1500x1500 km of cerrado and forest. The sophisticated MAS, AVIRIS and lidar multi-spectral, multi-dimension remote sensing devices measured with great detail the concentrations and radiative properties of smoke, clouds and fires. This ~100GB data base will help us to understand the effects of smoke aerosol on clouds and climate, not only in Brazil but in other tropical regions. Comparisons between the SCAR-B results with the properties of smoke and industrial/urban pollution in the US (measured in SCAR-A [Atlantic] and SCAR-C [California] experiments) will extend this knowledge to smoke and non-smoke aerosol and clouds in the mid-latitudes. This is a unique data base with no parallel.

Simultaneous with the ER-2 measurements, the University of Washington's Convair C-131A aircraft, with its unique capabilities, measured the detailed physical, chemical and radiative properties of smoke aerosol and trace gases and clouds. The aircraft, with its unique capabilities, is the most sophisticated flying laboratory ever brought to the tropics to study smoke aerosols and trace gases, their interactions in the atmosphere, and how they affect and are affected by clouds and radiation. This data base, collected during 100 hours of operation, also is unique and has no parallel for understanding the role of smoke on atmospheric processes and climate and for validating remote sensing approaches to be used by the Earth Observing System (EOS). The heavy smoke load, the ability to work in different parts of Brazil, and the successful operation of the mission of the ER-2 and the C-131A, made possible by the extraordinary help and guidance of the Brazilian Air Force observers, has made SCAR-B a great success. Measurements from the C-131A were complemented by those from the INPE Bandierante, which also sampled the properties of smoke aerosol and trace gases over the study region. These measurements, which have also been conducted in Brazil in the last several years in close collaboration between INPE, NASA and USFS, serve as continual multi-year observations of the properties, interactions and fate of smoke in the tropics.

An additional major component of SCAR-B is the network of sun/sky automatic radiometers which measure (and report via satellites to a receiving station in the US) the variability of aerosol loading, and its physical and radiative properties.

These measurements are combined with ground-based aerosol characterization by the University of Sao Paulo group. This is a joint NASA, INPE, and U. Sao Paulo operation which is continuing for its 4th year and is part of a global network of such instruments and measurements. The ground-based operation serves to generate aerosol climatology, to validate ER-2 observations, and to provide anchor points for the more detailed (but discontinuous) measurements from the ER-2, C-131A and the Bandierante.

The remaining component of SCAR-B is the meteorological and satellite data base. This component includes GOES satellite observations of the diurnal variability of smoke, clouds and fires (generated and provided by the University of Wisconsin group), and forecast and trajectory analysis by the INPE meteorological group which were synthesized in the excellent IBAMA facilities, to which we were welcomed, by scientists from U. Sao Paulo, INPE and NASA. AVHRR and Landsat images are also being archived. This component helped in planning individual science missions and for integrating and understanding, in a regional and multi-year sense, the results of SCAR-B.

The collaborative efforts by scientists from Brazil and the United States will be used in analyzing the data base. The first joint data analysis meeting will be held in May 1996 in the United States, with a more intensive first sharing of data sets to be held in Brazil during September 1996. Currently data is being organized and calibrated. MAS was recently at GSFC undergoing characterization in the thermal vacuum chamber. Results of this testing will be valuable for calibration of the SCAR-B MAS data set. Satellite data is being acquired both from U.S. and Brazilian sources.

5. Water vapor

The algorithm for remote sensing of water vapor was written.

6. Thin Cirrus and the 1.375 μm channel

Study of the use of the MODIS 1.37 μm channel for detection of thin cirrus over ocean and land was conducted. The information was summarized in a paper by Gao and Kaufman, and presented in the International conference on remote sensing in Paris. Preliminary method for correction of the cirrus effect over the land was developed using vegetation pixels.

6.0 Conferences

6.1 Chapman conference

Yoram Kaufman and Lorraine Remer attended and presented papers at the Chapman Conference on Biomass Burning in Wiliamsburg VA in March. The time there was also spent attending a SCAR-B planning meeting and an informal SCAR-C data analysis workshop. These formal meetings plus the informal discussions with many collaborators were important and acted to advance both the SCAR-B planning and organize the SCAR-C analysis.

7.0 Publications (written or published in 1995)

Gao, B.-C. and Y. J. Kaufman: "Selection of the 1.375 µm MODIS channel for remote sensing of cirrus clouds and stratospheric aerosols from space.", accepted for publication *to J. Atmos. Sci.*, 1995.

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Vermote, E. F. and Y.J. Kaufman, "Absolute Calibration of AVHRR Visible and Near Infrared Channels Using Ocean and Cloud Views", accepted to *Int. J. Rem. Sens.* , 16, 2317-2340, 1995.

Vermote, E. F., El Saleous, N. Z., Kaufman, Y. J. and Dutton, E. (1995), Stratospheric aerosol perturbing effect on the remote sensing of vegetation: Correction method for the composite NDVI after the Pinatubo eruption, accepted in Rem. Sens. Environ.